High Frequency Bottom Interaction in Range Dependent Biot Media

Ralph A. Stephen
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2583 fax: (508) 457-2150 email: rstephen@whoi.edu

Award Number: N00014-96-I-0460
http://msg.whoi.edu/msg.html

LONG TERM GOALS

The long term objective of this project is to understand the dominant physical mechanisms responsible for propagation, attenuation and scattering in low shear velocity, porous sediments such as found on continental margins. Many Navy acoustic systems operate at high frequencies in shallow water over soft, fluid-saturated sedimentary bottoms. In many environments the bottom has range dependent properties such as seafloor roughness or volume heterogeneities within the seafloor. To optimize the performance of these Navy systems it is necessary to fully understand the behavior of acoustic wave propagation and scattering in these complex environments.

OBJECTIVES

The time domain finite difference (TDFD) method has proven to be useful in studying acoustic wave propagation in complex media where other methods become invalid. We have extended our Numerical Scattering Chamber (NSC)(Stephen and Swift, 1994b), which is based on the TDFD method, to include poro-elastic effects based on Biot theory. One objective of this study is to validate the new code by comparing results with other methods for simple, canonical models.

With the extended code we will study propagation and scattering effects in real high frequency data from sedimentary environments. What are the dominant physical mechanisms responsible for propagation, attenuation and scattering in low shear velocity, porous sediments such as found on continental margins?

Prior work in non-porous media shows that scattering from wavelength size heterogeneities can be responsible for body waves in the sub-bottom that would not be predicted based on Snell's Law and ray theory using mean medium properties. This phenomenon will cause anomalous sub-bottom penetration and will be relevant for accurately predicting forward and back scatter from realistic environments. We anticipate that similar mechanisms will take place in fluid-saturated porous media and we need to quantify the effect of porosity on the bottom penetration issue. How far below the seafloor do we need to know geophysical parameters in order to accurately predict backscatter in porous environments?

APPROACH

Over the past twenty years we have developed finite difference methods for bottom interacting ocean acoustics in range dependent elastic and anelastic media. These methods are ideal for studying

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
30 SEP 2002

2. REPORT TYPE

3. DATES COVERED
00-00-2002 to 00-00-2002

4. TITLE AND SUBTITLE
High Frequency Bottom Interaction in Range Dependent Biot Media

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Woods Hole Oceanographic Institution,,Woods Hole,,MA, 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long term objective of this project is to understand the dominant physical mechanisms responsible for propagation, attenuation and scattering in low shear velocity, porous sediments such as found on continental margins. Many Navy acoustic systems operate at high frequencies in shallow water over soft, fluid-saturated sedimentary bottoms. In many environments the bottom has range dependent properties such as seafloor roughness or volume heterogeneities within the seafloor. To optimize the performance of these Navy systems it is necessary to fully understand the behavior of acoustic wave propagation and scattering in these complex environments.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

scattering from soft sediments in shallow water environments (Greaves and Stephen, 2000; Stephen, 1991; Stephen and Swift, 1994b). Because of the shear properties of the bottom and the strong lateral heterogeneity of most shallow water sediments, a fully elastic/anelastic wave code, such as the finite difference method, is necessary to unravel the complex physical mechanisms involved in propagation and scattering (Stephen, 1988; Stephen and Swift, 1994a; Swift and Stephen, 1994). NSC results can be applied to a broad range of frequencies because the spatial scales of heterogeneities are defined in terms of wavelengths (Stephen, 1996, for example).

In comparing the results of our TDFD code to the results from other codes for seafloor interaction, an important issue is whether the pores in the bottom are "open" to the water or are "sealed" from the bottom. In formulations which incorporate an explicit boundary condition at the seafloor (such as wavenumber integral and reflectivity approaches) this is a straight forward concept to implement. An advantage of the TDFD method is that it does explicitly consider boundary conditions. Heterogeneities of all kinds are included in the formulation by considering gradients in medium parameters within the appropriate wave equations. The concept of open and sealed boundaries is not easy to introduce into the wave equations used in our TDFD code (Biot, 1962 and Stephen, 1997, for example). We are studying the original derivation of Biot's equations from variational principles in attempt to resolve this problem.

Our models are constrained by physical properties measurements acquired from cores and drilling and the results will be compared to field and laboratory data sets including the SAX99 experiment. By considering range dependent porous media our technique will complement high frequency studies based on laterally homogeneous models.

This work is being carried out by Ralph Stephen, a Senior Scientist at WHOI, who is responsible for deriving and verifying the underlying differential equations, for writing the TDFD code, for defining test models, for assessing the results, and for presenting the results at meetings and in research papers. Stephen is assisted in this work by Tom Bolmer, an Information Systems Associate II, who maintains the network of workstations, writes input and output software, manages the data bases, prepares figures and assists in the preparation of meeting materials and papers.

WORK COMPLETED

A preliminary review of published formulations of the wave equations for heterogeneous, porous media was presented in Stephen (1997). We have a finite difference code for obtaining solutions to range dependent problems including poro-elastic media in two dimensions (see Figure 1).

We have modified our NSC code to include Biot media (Biot, 1956a; Biot, 1956b) and carried out preliminary tests. A thorough and detailed report of our approach for Biot media is outlined in Stephen (1987). In order to confirm the validity of our code for Biot media we are checking that our results are consistent with theory and we will compare our results for benchmark models to solutions generated by other methods. Preliminary results of our code and a review of related work in the field were presented at the Workshop on High Frequency Acoustics in Shallow Water in July 1997 (Stephen, 1997) and at the High Frequency Sediment Acoustics Workshop in July 2000. During these studies it became apparent that it is necessary to consider the gradients in porosity in the stress-strain relation for media with non-uniform porosity. Previous approaches including a number of published formulations overlooked this fact. The consequences for the accuracy of the numerical results have not yet been evaluated.

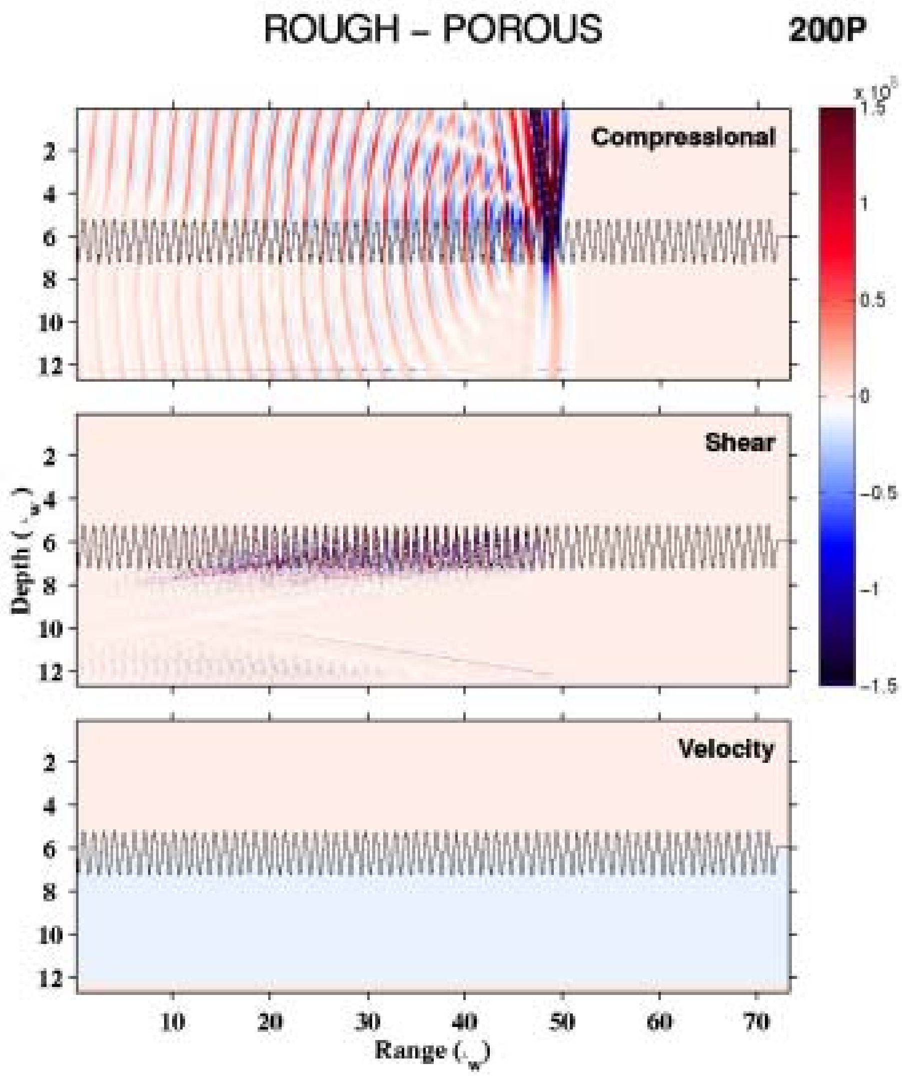

Figure 1: The top two frames of this figure show the compressional and shear wave fields generated when a Gaussian beam at 15° grazing angle insonifies a corrugated interface between a fluid and a porous solid medium. The roughness is sinusoidal with the amplitude equal to the compressional wavelength of sound in water (λw). The bathymetric wavelength is the Bragg wavelength for compressional waves in water (λw/cos(15°)). The grazing angle is sub-critical for fast waves in the bottom. The compressional field in the water consists of the direct wave, the reflected wave from the seafloor, and diffracted waves from the corrugations. The compressional field in the bottom consists of an evanescent wave and diffracted fast waves from the corrugations. There are no detectable converted or diffracted slow waves. The shear field in the bottom consists of incoherent converted and diffracted shear waves from the seafloor. There are also converted waves from the boundary between the porous region and the elastic substrate. The bottom frame describes the seafloor structure: the upper pink region represents water with a compressional velocity of 1500m/s and a density of 1000kg/m3, light blue represents a sand with 47% porosity and other parameters from Stoll and Kan (1981), and the lower pink region represents an elastic substrate with a compressional velocity of 1600m/s, a shear velocity of 120m/s, and a density of 2060kg/m3.

RESULTS

In previous work we obtained the first solution to diffractions from a heterogeneity at a fluid-poroelastic interface. The structure studied was a simple step on the seafloor. For an incident compressional wave in the fluid at sub-critical grazing angle, converted shear body waves and converted "slow" body waves were excited in the porous solid for just a flat interface. Scattering from the heterogeneity added diffracted compressional waves in the water and diffracted "fast", shear, and "slow" waves in the porous solid. This year the code has been applied to more complex bottoms such as the corrugated bottom shown in Figure 1. In this particular example neither the converted nor diffracted slow waves are a significant factor in the energy partitioning.

IMPACT/APPLICATIONS

We expect that our TDFD code will permit a quantitative study of the importance of porous media theory to propagation and scattering models in shallow water environments at high frequencies. Is porous media theory applicable to real problems? What are the best ways to define the necessary parameters for a porous medium? Are there alternative explanations for anomalous features in field data? What are the dominant physical mechanisms for scattering, propagation, and attenuation in heterogeneous porous media? These issues go well beyond seafloor acoustics and will have significant impact on the fields of physical acoustics, aero-acoustics and medical acoustics.

TRANSITIONS

None.

RELATED PROJECTS

None

REFERENCES

Biot, M.A. (**1956a**). "Theory of propagation of elastic waves in a fluid saturated porous solid. I. Low-frequency range," J. Acoust. Soc. Am. **28**, 168-178.

Biot, M.A. (**1956b**). "Theory of propagation of elastic waves in a fluid-saturated porous solid. II. Higher frequency range," J. Acoust. Soc. Am. **28**, 179-191.

Biot, M.A. (1962). "Mechanics of deformation and acoustic propagation in porous media", J. appl. phys., **33**, 1482-1488

Greaves, R.J., and Stephen, R.A. (**2000**). "Low-grazing-angle monostatic acoustic reverberation from rough and heterogeneous seafloors," J. Acoust. Soc. Am. **108**, 1013-1025.

Stephen, R.A. (**1987**). "A finite difference formulation of Biot's equations for vertically heterogeneous full waveform acoustic logging problems," in *Full Waveform Acoustic Logging Consortium Annual Report*, edited by M.N. Toksöz and C.H. Cheng, (Massachusetts Institue of Technology Earth Resources Laboratory, Boston), pp. 115-123.

Stephen, R.A. (**1988**). "A review of finite difference methods for seismo-acoustics problems at the seafloor," Rev. Geophys. **26**, 445-458.

Stephen, R.A. (**1991**). "Finite difference modelling of shear waves," in *Shear Waves in Marine Sediments*, edited by J.M. Hovem, M.D. Richardson, and R.D. Stoll, (Kluwer, Dordrecht), pp. 471-478.

Stephen, R.A. (**1996**). "Modeling sea surface scattering by the time-domain finite difference method," J. Acoust. Soc. Am. **100**, 2070-2078.

Stephen, R.A. (**1997**). "Time domain finite difference methods for range dependent Biot media," in *High Frequency Acoustics in Shallow Water*, edited by N.G. Pace, E. Pouliquen, O. Bergam, and A.P. Lyons, (SACLANTCEN Conference Proceedings Series, La Spezia, Italy), **CP-45**, pp. 501-508.

Stephen, R.A. (**2000**). "Optimum and standard beam widths for numerical modeling of interface scattering problems," J. Acoust. Soc. Am. **107**, 1095-1102.

Stephen, R.A., and Swift, S.A. (**1994a**). "Finite difference modeling of geoacoustic interaction at anelastic seafloors," J. Acoust. Soc. Am. **95**, 60-70.

Stephen, R.A., and Swift, S.A. (**1994b**). "Modeling seafloor geoacoustic interaction with a numerical scattering chamber," J. Acoust. Soc. Am. **96**, 973-990.

Stoll, R.D., and Kan, T.K. (**1981**). "Reflection of acoustic waves at a water-sediment interface," J. Acoust. Soc. Am. **70**, 149-156.

Swift, S.A., and Stephen, R.A. (**1994**). "The scattering of a low-angle pulse beam by seafloor volume heterogeneities," J. Acoust. Soc. Am. **96**, 991-1001.

PUBLICATIONS

Greaves,R.J. and Stephen, R.A., submitted. The influence of large-scale seafloor slope and average bottom velocity on low-grazing-angle monostatic acoustic reverberation. J. acoust. Soc. Am.,